PSRegional Fine-Scale Sequence Stratigraphy of the Woodford Shale and Its Impact on Microseismic Activity and Optimizing Future Hydraulic Fractures*

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Abstract

Microseismic study has been playing an important role in widening our view to explore unconventional reservoirs, characterize fracture networks, brittle ductile couplets, and well space scale heterogeneities. This study is focused on comparing the relationship between microseismic interpretation results from brittle ductile couplets identified from cuttings and stratigraphic framework. Interpretation of seismic alone could lead to a huge bias especially in unconventional reservoirs that are affected by high potential VTI and HTI (vertical and horizontal transverse isotropy). Correlation between microseismic and geologic data of the reservoir could strengthen the interpretation of results and filter out the pseudo-events displayed within the microseismic data.

The cuttings obtained from the microseismic treatment well and nearby well can be a good indicator of lithology change and geomechanical properties at certain depths. With fluctuations a horizontal well trace in the target window, the cuttings correspond with alternations of brittle and ductile couplets indicated by well log trends. Considering the microseismic event distribution, which mirrors the induced fracture network around the well bore, the identification of brittle and ductile zones improves. The results of interpretation help to locate the desirable zone with brittle properties and determine the future horizontal well drilling and fracturing scenario in the Woodford Shale.

References Cited

Cabarcas, C., and R. Slatt, 2014, Sequence stratigraphic principles applied to the analysis of borehole microseismic data: Interpretation, v. 2/3, p. SG15-SG23, doi: 10.1190/INT-2013-0151.1.

Maxwell, S., 2014, Microseismic imaging of hydraulic fracturing: Improved engineering of unconventional shale reservoirs: Tulsa, OK, Society of Exploration Geophysics, p. 197.

Slatt, R.M., and Y. Abousleiman, 2011, Merging sequence stratigraphy and geomechanics for unconventional gas shales: The Leading Edge, v. 30, p. 274–282, doi: 10.1190/1.3567258.

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Motivation:

Microseismic interpretation is a study utilized to evaluate the efficiency of hydraulic fracturing. How the activities distribute is affected by geomechanic property of the reservoir. Tying fine scale sequence stratigraphic knowledge with engineering stimulation activity can enhance confidence of characterizing and predicting the preferential fracture growth pattern and ultimately optimize the future hydraulic fracturing job (Cabarcas et al., 2014).

Available Data:

The data available for this study includes 1552 microseismic events location data separated by 12 stages along a horizontal well. The locations are obtained by surface array survey. Well logs and cuttings are available from one nearby vertical well and the treatment well, which landing within the Woodford Shale. XRF (X-Ray Fluorescence) data of cuttings are measured and calibrated.

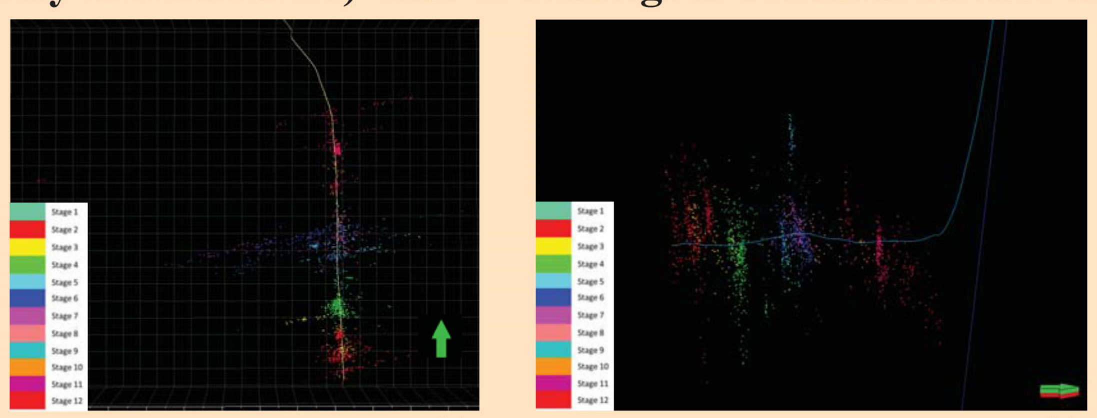


Figure 1. Microseismic events in (a) map view and (b) east view with horizontal and vertical well track. Events are colored by stages.

Methods:

In order to correlate microseismic events with the regional geology framework, a stratigraphic model was built up based on the well log (gamma ray) and XRF profile from both horizontal and vertical well. A brittle-ductile model also defined based on the stratigraphic framework and Young's modulus/ Poisson's ratio (Slatt and Abousleiman, 2011). The number and magnitude of microseismic are upscaled to both models to analyze the distribution trend.

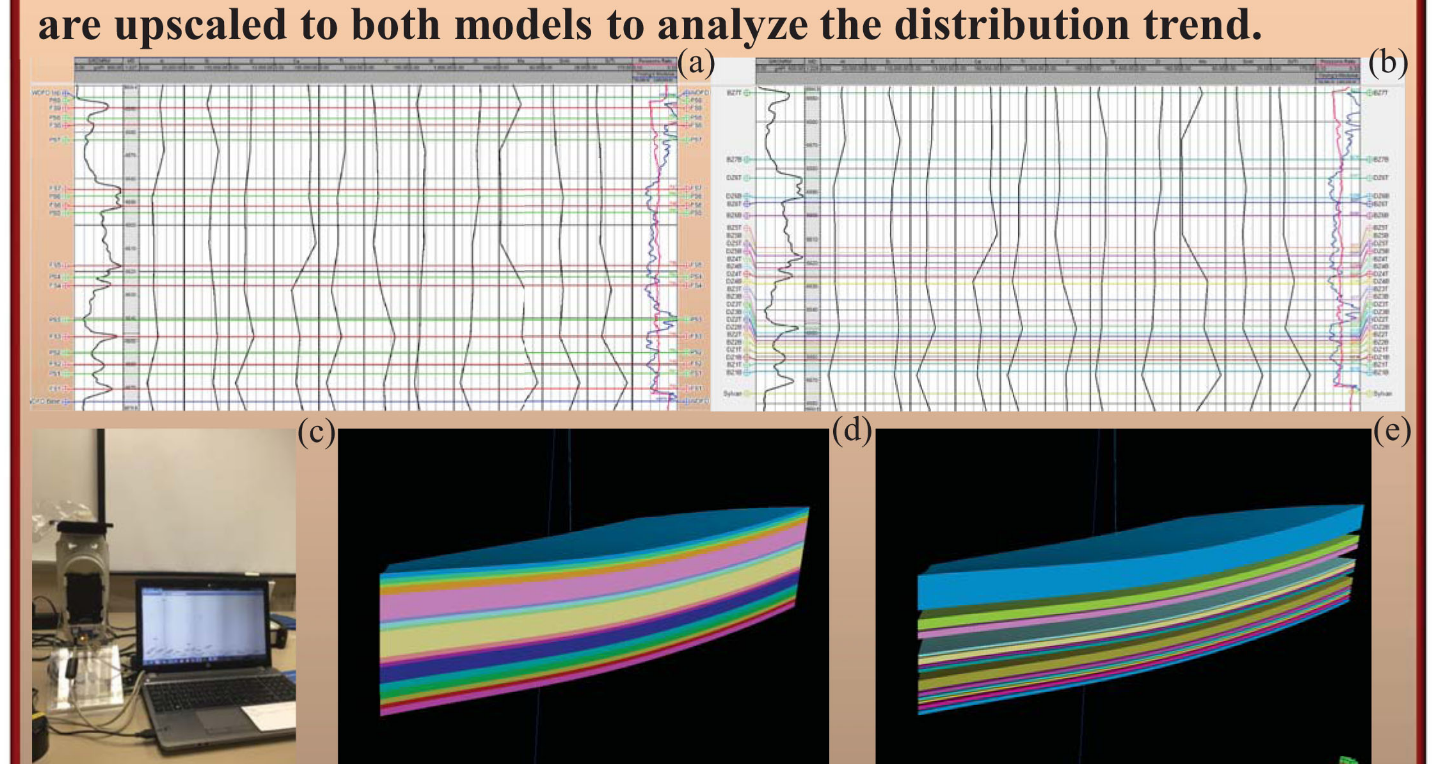


Figure 2. (a) Parasequence set from the vertical well, green lines are tops of each parasequence set, red lines stand for flooding surfaces, (b) brittle zone and ductile zone identified on the same vertical well. (c) HHXRF instrument used for measuring XRF profile of both wells. (d) regional sequence stratigraphic model and (e) brittle-ductile model with 10X vertical exaggeration scale.

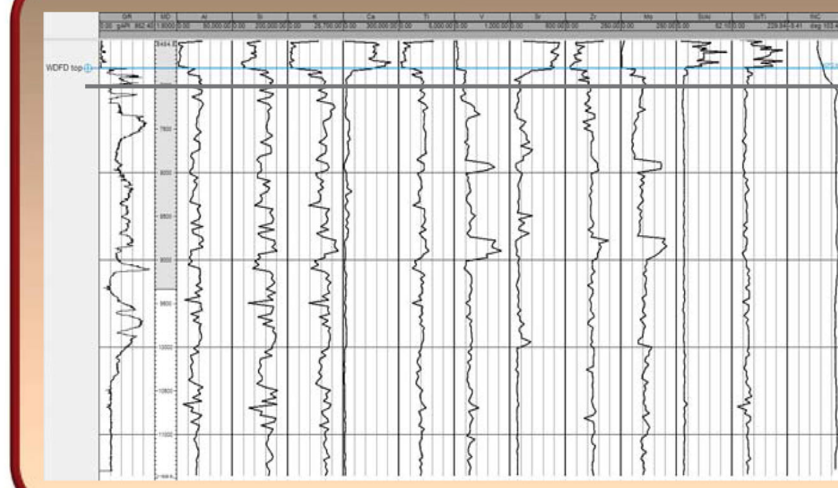


Figure 3. XRF and gamma ray profiles of horizontal well, landing section marked with gray line. Horizontal profile can be used as correlation tool to examine the uncertainty and horizontal anisotropy which is under the resolution of model generated by vertical profile. Above the landing surface, there is a maximum flooding surface identified by decreasing continental proxies (Al, K, Ti, Zr) and increasing anoxia environment proxies (V, Mo). Most sections along the horizontal track correspond with certain parts of the vertical section.

Interpretation Results:

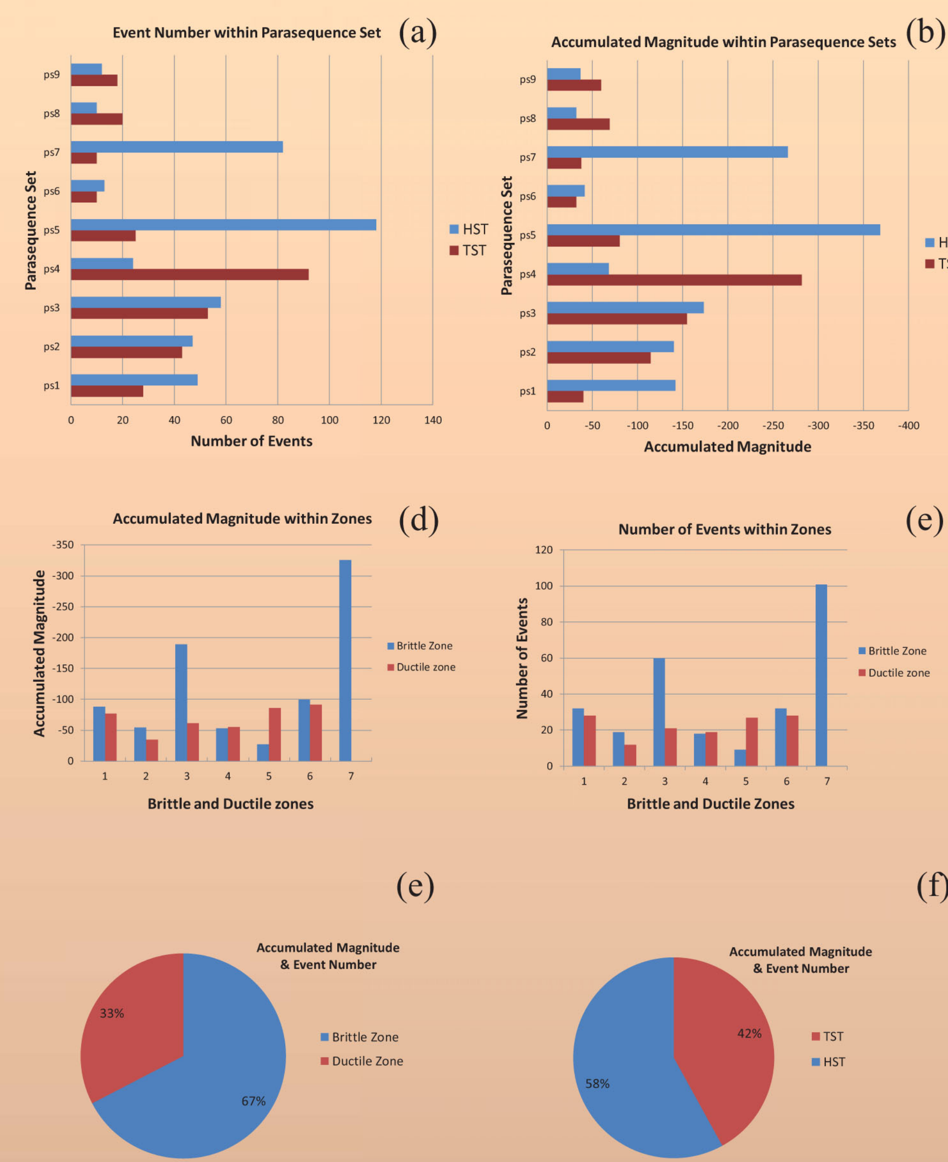


Figure 4. Upscaled the magnitude of all events within the Woodford, as shown in (c), the total magnitude and number of events within each zone of the two models are counted and compared. For sequence stratigraphic model, the number and accumulated magnitude have same trend in each zone, overall 58% events overall more events locates within locates within HST (Highstand System Tract), as shown in (f). Parasequence set 4 has more events in TST because of the low gamma ray, high brittleness at the base of the TST. In the brittle-ductile model, overall 67% events locate within brittle zone, as shown in (e). Brittle zone 5, which locates above the ductile zone 5 has less amount of events due to the thickness difference between two zones.

Figure 4. Schematic diagrams on the right is one of the most ideal hydraulic fracturing job. The well tract locates at significantly low gamma ray which not corresponds with any vertical profile and zones, interpreted as local continental deposit influx event. Perforation in brittle zone makes hydraulic fracturing more efficient also in the other adjacent zones.

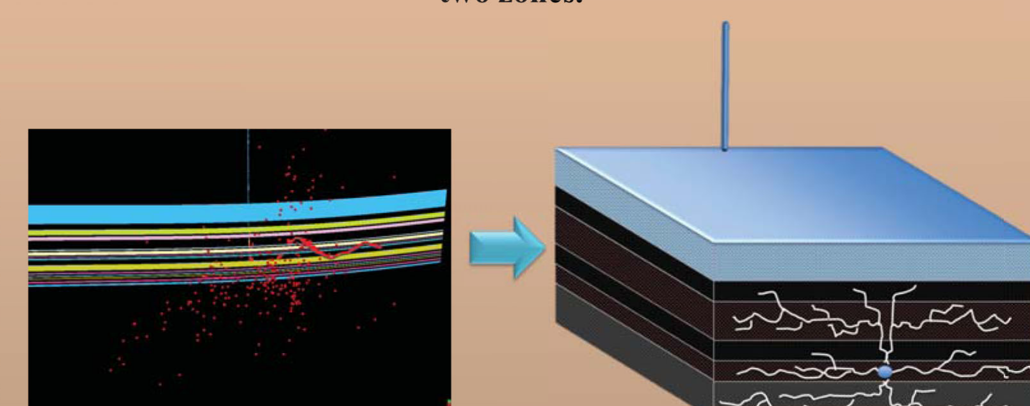


Figure 5. Schematic diagrams on the right is an ineffective fracturing job. The well tract locates in ductile zone 4, Perforation energy was absorbed so no fracture network grow horizontally along bed but only perforate vertically into adjacent non-reservoir formations (Sylvan shale and Mississippian limestone)

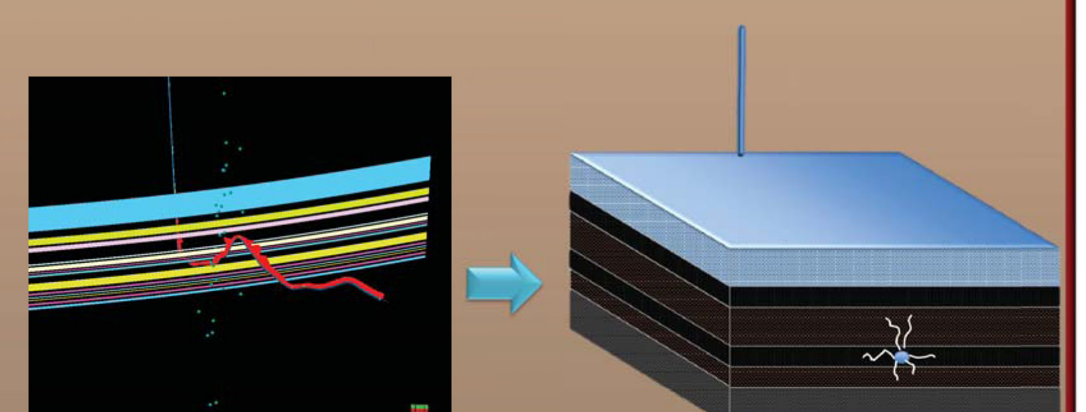
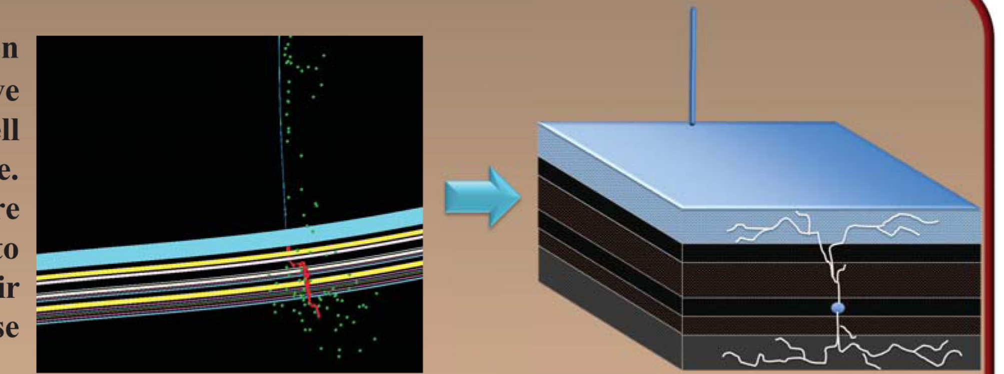


Figure 6. Schematic diagrams on the right is another ineffective hydraulic fracturing job, the well tract locates at ductile zone. Increasing in perforation pressure reach upward and downward to the brittle non-reservoir formations and grow within those formations.



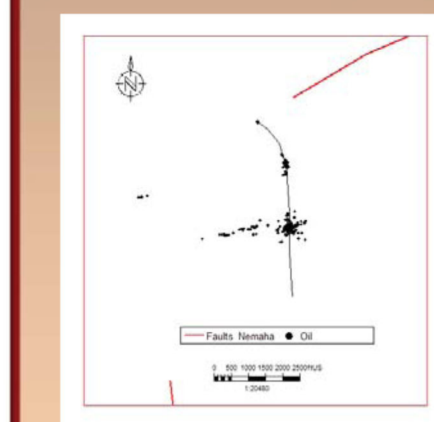


Figure 7. Near vertical faults around the study area also have impacts on growth pattern of induced fractures. There are two stages have obvious asymmetrical bi-wing geometry, the northern stage has discontinuous events distribution interpreted as either respond of subsurface fault activation or pre-existing natural fractures response along fault strike direction. Another southern stage's asymmetrical shape also proves that there is a pressure relieve zone near the fault area. Most stages have microseismic events extend with direction of N78°E, which interpreted as S_{hmax} orientation.

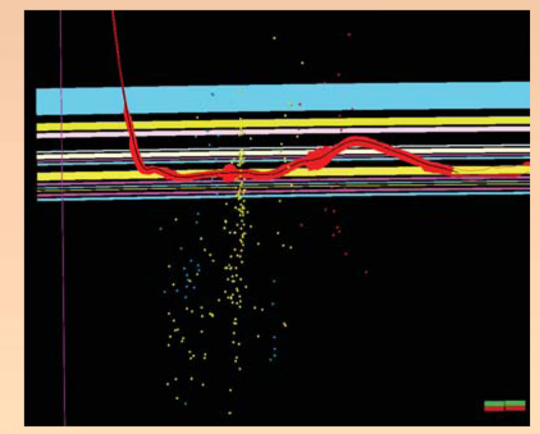


Figure 8. Three stages of microseismic events and brittle-ductile model intersect with V (above well track), Mo (below well track) log along the horizontal track. Note that there are three section with high Mo and V value interpreted as potential high TOC ductile zone, all three stages events develop around those ductile zone . The blue stage events are dipping towards south (left direction in this diagram) which interpreted as due to the pressure depletion from nearby vertical well (purple line on the left). (Maxwell, 2014)

Conclusions and Suggestions:

- Hydraulic fracturing jobs are more efficient when perforated in brittle zone, fractures grow along brittle bed easier than ductile beds. Ductile zone dissipate energy and fractures grow vertically.
- XRF and sequence stratigraphic models are helpful for interpretation and predict the microseismic distribution pattern.
- Hydraulic fracture growth patterns are highly impacted by reservoir anisotropy and local stress fields.
- S_{hmax} is oriented N78°E, so future neighboring horizontal well can drill along direction perpendicular to S_{hmax} in order to optimize the hydraulic fracturing job.

References:

- Slatt, R. M., and Y. Abousleiman, 2011, Merging sequence stratigraphy and geomechanics for unconventional gas shales: *The Leading Edge*, 30, 274–282, doi: 10.1190/1 .3567258.
- Mawell, S., 2014, Microseismic imaging of hydraulic fracturing: Improved engineering of unconventional shale reservoirs ,1st ed., p. 197, Tulsa, OK: Society of Exploration Geophysics.
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